

SST research Breaking new

Although manned supersonic flight was first achieved over a half-century ago, the goal of creating a commercially viable SST has proven elusive. Only two such aircraft saw regularly scheduled passenger service, but technical problems and environmental concerns put an end to them. Recent progress in addressing the main problem, noise, means a successful SST could be within reach.

Supersonic manned flight officially began with Air Force test pilot Capt. Chuck Yeager's October 14, 1947, flight of the experimental Bell X-1 research rocket plane over what is now Edwards AFB, California. Generations of increasingly fast and capable military aircraft followed, culminating in the 'supercruise' capabilities of the fifth-generation F-22 Raptor and F-35 Lightning II.

Bringing supersonic flight to commercial transport, however, proved far more difficult. Only two aircraft have flown regular commercial schedules—the Tupolev Tu-144 and the Aérospatiale (now EADS)/BAC (now BAE) Concorde.

Early struggles

The Tu-144 first went supersonic on June 5, 1969, and 10 days later became the first commercial transport to exceed Mach 2. What had seemed an edge for the Soviet Union turned sour with a crash at the 1973 Paris Air Show. This delayed its introduction into passenger service until November 1977, two years after Concorde. The next May, a Tu-144D crashed during delivery, and the passenger fleet was permanently grounded after only 55 scheduled flights.

The aircraft remained in use as a cargo plane for six years before being taken out


of commercial service after only 102 flights. It found limited use as a cosmonaut trainer in the Soviet space program, and for supersonic research by NASA, which conducted the Tu-144's final flight in 1999.

The first supersonic flight of the Concorde was on October 1, 1969, although it did not begin regular commercial flights until January 1976. The Tupolev's problems significantly reduced airline interest in supersonic transports, however, as did a major spike in fuel costs. And with environmental concerns about sonic booms soon leading to a ban on overland flights, the market essentially vanished.

The only U.S. operator was Braniff International Airways, which leased 10 Con-

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barriers



Lockheed Martin worked on concepts for NASA's N+ programs.

cordes—five each from British Airways (BA) and Air France—for subsonic flights between Dallas and Washington, D.C., with the European airlines then continuing the flights supersonically across the Atlantic. This lasted from 1978 to 1980, ending when the plan proved unprofitable, leaving BA and Air France as the only full-service operators. The two announced simultaneous plans to retire the Concorde in 2003—Air France in June and BA in October.

Progress at last

Now, nearly a decade after the last SST passenger flight, research into resolving Concorde's major problem—noise—is beginning to show significant progress.

Major NASA-led programs in recent years include N+1 (near-term sonic boom reduction), N+2 (technology ready for use in 2020-2025), N+3 (2030-35), LANCETS (lift and nozzle change effects on tail shocks), Quiet Spike, SCAMP (superboom caustic analysis and measurement program), WSPR (waveforms and sonic boom perception and response), FaINT (farfield investigation of no boom threshold), and the USAF/Lockheed Martin X-56A MAD (multiutility aeroelastic demonstration), which NASA took over for supersonic research in 2012.

The Air Force, the Navy, and industry also have been working to improve supersonic aircraft, though military requirements only partially mesh with the commercial work at the heart of NASA's programs.

"There have been a number of collaborative efforts in terms of CFD tool development and design system development that share information between the Air Force and NASA," says Peter Coen, project manager for NASA's Supersonic Fundamental Aeronautics Program (FAP). "In addition, low-complexity, highly efficient stable inlets are applicable for both supersonic military and commercial aircraft, although the eventual shape will be different," he says.

"Another overlap developing a little momentum is [that] both the Air Force and

Boeing offered the 2707 as competition for the Concorde, but interest in supersonic travel fell by the wayside.



Navy are taking into consideration takeoff and landing noise, not just in terms of community compatibility, but also long-term effects on military personnel. So we're working with the Navy on a basic understanding of the application of some noise reduction technologies to supersonic jet flow," Coen tells *Aerospace America*.

Both Lockheed Martin Skunk Works and Boeing Research and Technology (formerly Phantom Works), where the two conduct advanced research, have worked with NASA on the N+ programs, drawing on (or in some cases continuing) their own internal research as well as previous military and commercial supersonic programs.

The future SST

While Lockheed Martin's recent efforts date back to the early 1990s, N+2 program manager Mike Buonanno says that his is the only supersonic research the company currently has under way.

"The research we're doing now is in support of a future SST," says Buonanno. "Under the N+2 contract, one of the things we are doing for NASA is a conceptual design study for a future SST and what technology needs to be matured to make such a vehicle viable economically, so that it has

useful range and fuel consumption and has sonic boom characteristics that can allow it to operate over land.

"We selected Mach 1.7 as our target [compared to Concorde's Mach 2.1]. We were given a range of passengers—at least 30 or more. Based on our research, we thought 80 would be a good number to target. We're designing to be compatible with international airports, in terms of runway length and a range of over 5,000 n.mi. That would allow some transpacific routes, which would not require sonic boom compliance. For low-boom cruise, we're designing for at least a 4,000-n.mi. range, although we think we can do better than that."

Boeing completed its N+3 studies in 2010 and more recently has concentrated on pushing the N+2 technology readiness level (TRL).

"We've continued to conduct research into low sonic boom supersonic aircraft concepts to reduce the noise levels to the point where supersonic operations over land would be possible. In addition, we are continuing to investigate future market opportunities relative to our product line, as well as technology research in structures, materials, propulsion, and systems," says Robert Welge, Boeing senior technology fellow. "The N+2 and N+3 studies are focused on concepts that potentially could be feasible in 2020-2035, but it's unknown if any of these concepts will ever actually become new airplanes.

"There are at least 15 years until there could be any notional introduction of any of these concepts into service. In that time, Boeing and other market participants will continue to develop and market new concepts. For our part, Boeing is always interested in expanding the technology base for our future products, and we are continuously engaged in studying a variety of future 'concept planes' to help guide technology development and understand potential future products and markets."

Both U.S. companies were part of the nation's early effort to compete with the European Concorde, offering the Lockheed L-2000 and Boeing 2707 into competition for a congressionally funded American SST. Boeing won that competition, but in 1971 Congress halted funding and banned all overland supersonic transport flights. Neither company opted to pursue an independent development.

"We're working on it, so we're interested in the technology and moving it for-

An ironic record

In 27 years of passenger flights, the 14 Concorde's in regular passenger service recorded 4,358 flights with only one accident: the July 2000 crash of an Air France flight on takeoff, attributed to a tire blowout caused by a piece of metal that had fallen off another aircraft as it took off just ahead of the Concorde. With neither of the Tupolev crashes having involved passengers, that record leaves SSTs with the safest flight record (in miles per passenger) of any commercial jet transport, an ironic legacy considering airline safety concerns in 1977.



ward,” Welge says. “NASA is currently targeting a date of 2025 with N+2 and, based on the TRLs, that’s still the date we’re looking at for this type of aircraft. No one technology by itself will get us where we want to be, but by integrating them all we can come up with a vehicle that is more than double the speed of today’s subsonic airliners and still environmentally responsible.”

Current focus

“The technology exists to make an SST today—it existed 60 years ago,” says Welge. “There are no showstoppers now, and the level of environmental impact and efficiency will improve with time. On N+2, we’re really focused on a jetliner similar to today’s commercial airliners. We think there is a large domestic market for this type of aircraft, which would be a big enabler compared to Concorde. You could fly coast to coast with an acceptable low boom level and get from L.A. to New York in about 2.5 hr; we think there would be a big market for that as well as the international traffic.”

Gulfstream, which has been doing supersonic research since the 1980s, is most interested in the potential for a supersonic business jet—which all parties involved believe to be the most likely first application of the technologies NASA is investigating. As with a larger SST, however, the current emphasis is on resolving the sonic boom.

“We do supersonic research because speed is likely the next technological step in air travel,” says Robbie Cowart, director of supersonic technology development at Gulfstream. “There’s been an industry push to bring supersonics to the forefront of research to develop a sonic boom standard and a rule governing environmentally efficient supersonic flight over land.

“Gulfstream, NASA, and the rest of the industry continue to conduct research into sonic boom mitigation. A supersonic jet won’t be introduced until the current regulations prohibiting supersonic flight over land change. If a rational rule could be put in place a supersonic airplane could come into existence in the next 20 years or so,” says Cowart.

Boeing too sees the likely future of supersonic passenger transport as an evolution beginning with business jets.

“Many factors have to be considered, including whether or not the current pace of research can be maintained and whether sonic boom levels are considered to be acceptable for the public. The ongoing NASA



NASA's F-15B testbed aircraft flew in the first evaluation flight of the joint NASA/Gulfstream Quiet Spike project, which seeks to verify the structural integrity of the multisegmented, articulating spike attachment designed to reduce and control a sonic boom. Credit: Lori Losey.

technology studies we and several other industry teams are supporting have been looking at several technologies that could be available in 2020-2035,” Welge says.

“From a technical standpoint, low sonic boom supersonic business jets could be feasible around or shortly after 2020, and low sonic boom airliners could be feasible around 2030-2035. Boeing has a continuing interest in technologies that could eventually enable a next-generation supersonic airliner that would be viable economically, environmentally, and operationally.”

Chicken or egg

As research toward future SSTs continues, some see it becoming a ‘chicken or egg’ situation, with industry reluctant to build a true supersonic demonstrator until the FAA sets out regulatory standards for overland flight, and the FAA apparently waiting for industry to demonstrate what can be done to mitigate the problem.

“The first step is a demonstrator, and most projections have it flying in the next 5-10 years. We’ve done a lot of testing already with military aircraft; with a demonstrator, we would want to do many of the same tests, such as the air-to-air probes. We’re working on all the individual components now, but need to bring those together and get something flying,” says Larry Cliatt II, principal investigator in the FaINT program at NASA Dryden.

“It would be more difficult to predict when we might actually see a production aircraft flying. The first probably would be a business jet, probably at least five years before a jetliner. How big can you get, how fast can you fly, with what level of boom on the ground, and still be profitable? But will the FAA set a standard first and industry design toward it, or will the FAA wait until there is a demonstrator and base a regulation on what results come from it?”

Anatomy of a boom

One outcome of research in recent years has been the need to understand the vari-



Chuck Yeager

ability of sonic booms, and that a resolution to one type might not mitigate—or might even worsen—other boom elements. FaINT is designed to investigate some of those factors, from cause to intensity to ‘shape.’

“Overall, the project is investigating the different sonic boom phenomena. One is Mach cutoff, where the sonic boom is fragmented above the ground, but right below the fragment line you still get waves that propagate to the ground—usually as a distant rumble, like thunder. So we wanted to correlate that with different flight conditions, as well as validate future computer codes using that data,” Cliatt says.

“Another phenomenon is lateral cutoff related to the sonic boom carpet, which is the primary sonic boom, with the boom being lateral to that even if the carpet does not actually hit the ground. The carpet is what people typically hear—an in-wave sonic boom, which depends on the size of the aircraft, altitude, speed, etc.”

FaINT used a specially equipped F/A-18 flying different supersonic profiles over a large field of 120 microphones laid out on the lake bed at Edwards AFB. Thirteen flights, averaging six sonic boom passes each, took place between October 29 and November 7, 2012, in the program’s Phase 2. A second aircraft, a TG-14 motorglider, recorded midfield booms above the atmospheric turbulence between 5,000 and 10,000 ft msl (mean sea level). An additional vertical component was provided at about 3,000 ft by a blimp from Cessna.

Phase 1 project design, Phase 2 flights, and final Phase 3 data analysis have recently drawn wide support from both do-

mestic and international partners, including Gulfstream, Boeing, Cessna, Penn State, NASA Dryden and Langley, and aviation agencies in Japan and France. Their intent was to measure not only the boom most people recognize below the aircraft, but also booms that may develop above the plane and hit the ground hundreds of miles downrange, and also to study how variable factors can impact different forms of boom.

“I think we can say with confidence that the sensitivity of these Mach cutoff cases is very high. We were looking at what boom levels were heard on the ground, depending on what the aircraft was doing, and we found that very slight changes could impact the kind and level of boom. If the F-18 was flying at Mach 1.1, all we might hear on the ground was a low rumble. However, if the pilot did the same maneuver, only flying 4 kt faster, we might get a full boom,” Cliatt points out.

“Atmospheric conditions also have a very big effect. If we did a flight at 7 a.m., the boom might not hit the ground; fly the same maneuver 2 hr later and the boom might hit the ground or be louder. So as we move forward, we have to take that and other factors into account in real time for any kind of sonic boom mitigation technology,” he notes.

While FaINT and other programs using existing aircraft have revealed a great deal, he says, they cannot do all that is needed to move from basic experiments to TRL 6 (system/subsystem model or prototype demonstration in a relevant environment) and TRL 7 (system prototype demonstration in an operational environment).

“We always have more research to do: turbulence modeling, how turbulence in the atmosphere affects sonic booms, and over-the-top sonic boom research. The primary carpet is produced by shock waves beneath the aircraft, but you also have some that go up into the atmosphere, then come back down hundreds of miles from where the aircraft might be. For example, the Concorde would slow down to subsonic when approaching land, but the over-the-top boom still might hit the ground hundreds of miles ahead of the aircraft,” he says.

Need for a demonstrator

“There are different ways of dealing with booms, but until someone builds a low-boom demonstrator, we might not know for sure the best way to address it. Certainly aircraft shape can be changed to lessen

NASA’s F/A-18B mission support aircraft 852 flew over the high desert near the Tehachapi Mountains northwest of Mojave as part of a series of low-supersonic, high-altitude flight profiles during the FaINT flight research project at NASA Dryden. Credit: NASA/Jim Ross.



booms hitting the ground; there also are real-time changes that could be made. For example, NASA is working on a sonic boom cockpit display that would show the pilot, in real time, what kind of booms the aircraft is producing, so he could tailor his flight profile,” Cliatt explains.

And that, NASA and industry agree, is the level of technology development now needed to move supersonic research to the next level, making any form of SST viable.

“Right now, I think we have the tools and knowledge to move forward and build aircraft that have lower sonic boom levels. We’ve done engine research and shaping the aircraft to manipulate the boom on the ground,” Cliatt says. “The next step is to make something at scale and fly it.

“Most of the industry is trying to determine acceptable levels for sonic booms on the ground. Right now there is no FAA or ICAO [International Civil Aviation Organization] legislation regarding a threshold. So a lot of what we are doing now is building a data set to help determine that. That is one of the problems—no one wants to build a demonstrator until they know what levels the FAA wants.”

While various research efforts are expected to continue, the ultimate future for development of a production SST in the next two or three decades now appears to rest heavily on a specially built supersonic demonstrator.

“If we can’t solve the boom problem, there is no sense working the other issues, because the airlines won’t buy an aircraft they can’t fly wherever they want to,” FAP’s Coen points out. “If and when we start flying a low-boom demonstrator, I believe the boom noise in urban environments won’t be a problem, but it will be more so in rural environments, and especially in the extreme quiet environments like the Grand Canyon and national parks. Which is where the regulators will step in and determine if there is sufficient value to override any of that.

“The N+2 time frame, at the rate we’re going, doesn’t give us all the technologies we need to achieve a completely acceptable level of boom, efficiency, and affordability. I don’t think we really have to wait until 2035, but 2030, if we continue at the current rate, is possible. And I think the business jet market, even with technologies available in the 2025 time frame—provided we can resolve the overland boom—could see a product built. The boom is key. We’ve made progress and are getting to the point



Icon II is Boeing’s concept for an N+3 SST configuration. Boeing research concluded that N+2 SST concepts are unlikely to meet fuel efficiency and sonic boom mitigation goals at the same time, so they identified a preferred N+3 concept that shows the potential to meet or exceed nearly all the NASA goals for N+3.

of a flight demonstrator to develop the data for a regulatory process. That is the goal of the project now and, funding willing, we’ll get there,” Coen says.

Change and restructuring

NASA’s research continues to focus on sonic boom mitigation, takeoff and landing noise, high-altitude emissions, lightweight and durable structures and materials for engines, and aeroelasticity for long, slender SSTs. But the future of NASA-sponsored research, he adds, will see some significant changes as the agency undergoes yet another reorganization.

“Starting in FY13, there will be restructuring within the FAP, and a lot of the work in supersonics will become part of the High Speed Project. The primary reason for that was a decision for NASA to ramp down its hypersonics research and create projects with a little more procurement available for testing and higher TRL effort. So we created an Aeronautical Sciences Program that deals with a lot more cross-cutting technologies applicable across the speed regime and multiple vehicle types,” Coen says.

“FAP is doing the fundamental, lower TRL research to enable new concepts, technologies, and vehicles for atmospheric flight. We are not doing a lot of the higher TRL demonstrations, but are focused on removing the barriers to practical civil supersonic flight. Most of our recent work is more focused on the N+2, but the more foundational work primarily addresses the N+3. We are working on technologies such as shaping the aircraft to reduce sonic booms, nozzle concepts for low takeoff and landing noise, and some CFD-based design methodology that would allow us to address boom reduction and efficiency enhancement simultaneously, by modeling and designing the full 3D shape of the aircraft.” ▲